38 HART Networks

DAVID S. NYCE

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TYPICAL PROCESS CONTROL AND FACTORY AUTOMATION I/O PRODUCTS

With over 20 HART device categories, detailing their individual parameters here is not practical. So, listed below alphabetically, are general categories and types of devices available.

Actuator/Positioner: Linear and rotary actuators (positioners) are available, with positioning power supplied from electric, hydraulic, or pneumatic power sources. Some types include valve positioners, electropneumatic positioners, electric actuators, and hydraulic positioners. In these devices, Nominal 24 VDC electrical power supply is typical.

Analytical: Transmitters are available for gaseous oxygen, dissolved oxygen, pH, conductivity, humidity, combustible gas, and others. Power supply of 24 VDC is typical.

Calibrator: Handheld communicators/calibrators, documenting process calibrators, intrinsically safe calibrators, and calibration management software. Handhelds are typically battery powered, and can provide power to the HART device that is being calibrated.

Density: Nuclear density transmitters, specific gravity transmitters, and density meters (aka densimeter, densitometer). Nominal 24 VDC power is typical.

Flow: Coriolis mass flow transmitters, variable area flow transmitters, magnetic flowmeters, vortex flowmeters, and electromagnetic flowmeters. Nominal 24 VDC power is typical.

Level: Liquid level transmitter, buoyancy transmitter, ultrasonic level transmitters, hydrostatic level transmitters, radar level meters, magnetostrictive level transmitters, nuclear level transmitters, and capacitive level transmitters. Nominal 24 VDC power is typical.

Pressure: Gauge pressure transmitter, absolute pressure transmitters, differential pressure transmitters, and critical pressure transmitters. Nominal 24 VDC power is typical.

INTRODUCTION

The HART® (an acronym for Highway Addressable Remote Transducer) communication protocol was originally developed by Rosemount in 1985 to make improvements to the popular two-wire 4–20 mA transmitter system by adding the capability of digital communications. The HART Users Group was formed in 1990. Ownership was transferred to the HART Communication Foundation (www.hartcomm.org), a not-for-profit membership organization, in 1993 [1].

The HART communication protocol utilizes the traditional 4–20 mA current loop industrial standard, and adds an open multi-master protocol for the bidirectional communication of digital data. All field devices with HART protocol have both means of communication: HART communication and the traditional current loop. HART is often called a digitally enhanced version of 4–20 mA instrumentation, although the digital information is communicated via analog technology. This is accomplished by impressing an AC carrier onto the wires of the current loop, and is called Bell 202 Frequency Shift Keying (FSK). The current loop signals occur in the frequency band between 0 and 25 Hz (but usually at around 10 Hz), while the much higher frequency range of HART communications [2] (i.e., the FSK frequencies of 1200 and 2200 Hz) ensure that the two types of signaling can coexist without interfering with each other. Hart digital communication is half-duplex, which means that both transmit and receive functions are supported, but not at the same time.

A HART data transaction comprises a master command followed by a slave response. Communication access is governed by token-passing among the devices on a channel (i.e., a channel is a pair of wires). The transmitted message includes the information for the next passing of the token. If no communication takes place within a preset time period, the token expires, and control of the channel is open again [3].

HART devices and networks are widely implemented in process control, industrial automation, power generation facilities, pulp and paper mills, and oil pipelines, as well as being commonly used in a variety of other industrial environments where digital signaling rates of several times per second are acceptable. HART devices include sensors and other measurement (input) transducers, as well as actuators or positioners and other output transducers. They can be implemented as one device per twisted pair of wires, as in a traditional 4–20 mA installation, or a field device can be "parked" at 4 mA and networked, with up to 15 devices connected in parallel across one twisted pair (or more than 15 devices, in systems implementing a "long form" address, described later). When networked, they communicate only through transfer of digital information, because the analog 4–20 mA current of each device is "parked" at 4 mA for all devices on the network. HART is somewhat in competition with Foundation Fieldbus (FF), and the selection of which of these two protocols to implement is often dictated by the requirements of the specific application and any preexisting installation (further information about making such a selection is presented later in this section, and FF is detailed in Chapter 39.

BACKGROUND

When instrumenting an industrial process, factory automation, or power generation facility, etc., it is necessary to measure process parameters using sensors and measurement transducers, for which the 4–20 mA signal is an output, and to report the resulting information to an appropriate measurement and control system. When it is determined that an adjustment to the process is needed, information is sent to actuators and other output transducers, for which the 4–20 mA signal is an input, to drive them in order to effect the desired adjustment and thereby maintain control of the process. At other times, it may only be necessary to indicate or record process parameters, rather than control. The HART communication protocol is one standard for transferring such information among various parts of a system. When individually connected (i.e., not networked), the traditional analog 4–20 mA current signal is available. By controlling the loop current, a traditional 4–20 mA transmitter reports the value of a single process variable (PV) to the control system, or other receiving equipment. With HART, however, the primary PV can be communicated through the loop current and digitally, as well as communicating additional Secondary, Tertiary, and Quaternary PVs (SV, TV, QV respectively) digitally, and adding other valuable capabilities described below.

In an individual configuration (i.e., not networked), digital information can also be sent to and received from the field device. FSK information is superimposed upon the analog current signal, while not affecting the integrity of the current signal. As an example of the other valuable capabilities mentioned above, the digital communication can be used to query the field device of its type (e.g., pressure transmitter), its measurement range (e.g., 0–50 PSIG), and the actual signal amplitude presently being reported (e.g., 5.203 mA) via the current loop. In addition, many HART devices can also be calibrated, error-checked, and re-ranged by sending appropriate commands to the device. In this operating mode (i.e., not networked), the normal 4–20 mA analog signal is available, and provides the fastest signal response time, which is usually around 10 Hz.

When networked, up to 15 devices, but the number can be greater, depending on the capability of the particular device's design, since a "long frame" address can support up to 256 devices can be connected across one pair of wires. In this networked configuration, measured information from a sensor or control signal to an actuator is accomplished only through the digital data. That's because every device on the network is parked at a constant 4 mA. Since HART devices are used with the same physical connections of a traditional current loop transmitter, it is important to first become familiar with the various connections of such devices.

TRADITIONAL 4–20 mA CURRENT-LOOP TRANSMITTERS

A basic implementation of the traditional 4–20 mA system comprises a transmitter, a power supply, receiving equipment, and usually, a load resistor (Figure 38.1). "Transmitter" is the commonly used term for a sensing device or transducer having a 4–20 mA current output signal. The two-wire transmitter is the most common configuration. This means that the transmitter internal electronics must require less than 4 mA to operate, and then current is added as needed so that the total current in the loop varies between 4 and 20 mA, depending on the value of the measurand. Four milliamperes is indicative of the signal "zero," while 20 mA is indicative of "full scale." This way, a single pair of wires is supplying power to the transmitter, as well as carrying the signal information. The difference between zero and full scale (i.e., 16 mA) is called "span."

Connecting a 250 Ω load resistor converts the 4–20 mA loop current to 1–5 V, since the receiving equipment is usually designed to measure a voltage signal.

The load resistor is typically a precision resistor of 250 Ω, 0.1% or better, with a power dissipation rating of at least 0.25 W. With a loop current of 20 mA, the power dissipation of a 250 Ω resistor is 0.1 W, but a safety factor is allowed to minimize the temperature rise of the resistor. This reduces any added error due to temperature sensitivity of the resistor. Also, currents of slightly more than 20 mA are allowed for indication of error detection. Normally, only two wires are used to form the "current loop" that supplies power for the transmitter and carries the signal. Since the transmitter electronics must require less than 4.0 mA in order to function, there are some limitations on the types of sensors and electronics that can be used, as well as how often readings can be updated. Besides providing the advantage of requiring a total of only two wires, using a twisted pair of wires also reduces the susceptibility to electrical interference. That's because currents induced by local magnetic fields and voltages picked up from nearby electric fields will affect both wires similarly, and have zero net effect on the (differential) signal level. Another advantage of sending a signal by analog current instead of analog voltage is that the resistance of long

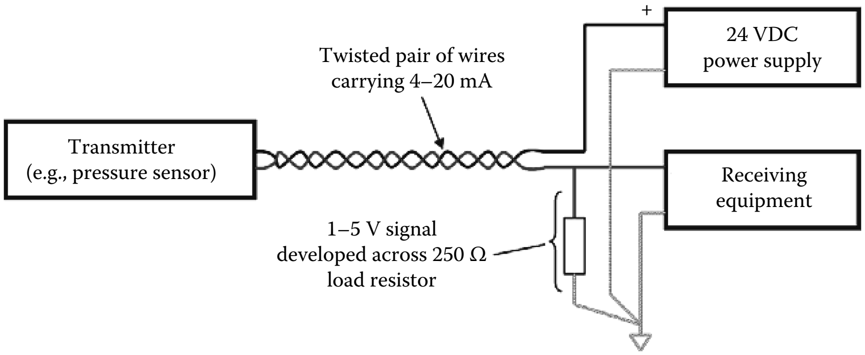
+
24 VDC power supply
Twisted pair of wires carrying 4–20 mA
Transmitter (e.g., pressure sensor)
Receiving equipment
1–5 V signal developed across 250 Ω load resistor

FIG. 38.1
Typical transmitter connections, with a precision (e.g., 0.1%) 250 Ω load resistor.

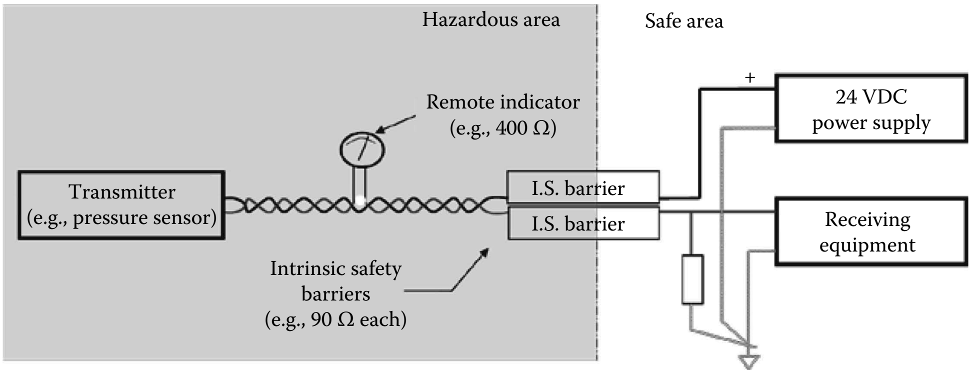

FIG. 38.2
Transmitter connection with load resistor, and more than one resistance inserted along the current loop.

wires leading to the receiving equipment will not degrade the signal. Whereas a voltage signal would suffer from a voltage drop due to measuring currents multiplied by the resistances of the long wires (IR voltage loss, and I^2R power loss).

It is common for process transmitters to offer the capability of 10 to 1 "turndown," as well as zero elevation or suppression. Turndown means adjusting the PV measurement span for a smaller amount within the available range of the transmitter, while still maintaining a specified accuracy. For example, a 0–50 PSID pressure transmitter range can be "turned down" to having a range of only 0–5 PSID scaled to produce loop currents of 4–20 mA (for a 10:1 turndown). Zero suppression or elevation is offered up to 50% or 100%. For 50% elevation, for example, the transmitter mentioned with a normal 0–50 PSID range can be adjusted so that the 4–20 mA loop current corresponds to 25–75 PSID. Or, if suppressed by 50%, the 4–20 mA loop current would correspond to −25 to +25 PSID (accordingly, 0 PSID would produce 12 mA of loop current).

Some 4–20 mA process sensing devices use a three-wire connection, in which power is supplied over one wire, the second wire is the return wire (often called "ground"), and the signal current is sent out on the third wire. This allows the use of devices that require more than 4 mA to power them. The wiring of these devices can vary somewhat, so it is best to consult the wiring diagram supplied by the manufacturer in the data sheet for the given field device.

The receiving equipment can measure the 4–20 mA signal directly, but it is typical that a 250 Ω "load resistor" is connected as shown in Figure 38.1. This resistor is often included within the receiving equipment, and would then not need to be added by the equipment installer. Since the resistor converts the 4–20 mA into a voltage signal of 1–5 V, the electronic circuits within the receiving equipment will be measuring a voltage signal instead of current. The HART specification requires a minimum loop impedance of 230 Ω. This impedance allows the FSK signals to be impressed upon the loop current signal. HART also specifies a maximum loop impedance of 1100 Ω, but the maximum loop impedance is also limited by the power supply voltage.

The placement of additional resistances within the current loop is shown in Figure 38.2. Such resistances commonly include resistive intrinsic safety (IS) barriers and/or remote indicators. This example has 830 Ω of added loop resistance, not counting the resistance of the wire.

Adding loop resistance will not affect the loop current as long as the total loop resistance is not more than the maximum allowed for the system (provided the loop resistance does not exceed the 1100 Ω maximum for HART communications). For example, if the loop power supply is 24 VDC and the transmitter requires at least 6 V for operation (this is given in the manufacturer's data sheet for the field device), then the voltage compliance available for loop resistance is 18 V. At 20 mA, that's equivalent to a maximum loop resistance of 900 Ω. With such a transmitter, the data sheet would probably state a maximum loop resistance of 850 Ω with a 24 VDC supply, to allow a small safety factor. That means that with a 250 Ω load resistor, one can install up to 600 Ω of additional loop resistance in this example. This loop resistance includes wire resistance, IS barriers, remote indicators, etc. Although 24 VDC is the typical power supply voltage, a higher power supply voltage will support a greater loop resistance. Sometimes 30 or 36 VDC is used, but the transmitter and any safety barrier devices must also be rated for that voltage.

PROCESS VARIABLES

Multivariable field devices can provide more than one digital PV to the control system. The additional PVs can be additional measurements, or some can be calculated. For example, a pressure transmitter can also be fitted with a sensor to measure temperature, and it can then be possible to calculate level and/or volume (if supplied with strapping tables for the particular vessel, and a specific gravity vs. temperature table for the measured liquid). With some pressure transmitters, the Primary PV, and the current loop, can be mapped to be either the pressure or the level, for example. Support for device variables in multi-variable field devices was added to the HART specification with revision 7.0.

HART NETWORK CONNECTIONS

When field devices are connected in a HART network, they can be multi-dropped, as shown in Figure 38.3. For clarity, the twisted pairs are no longer shown as such. The Master is assumed to contain the power supply for the network.

Multi-dropping requires that the field devices be parked, usually at 4 mA. The master can configure each field device, and communicate with it. A handheld device can also be connected at any place along the network wiring, but access is usually only available at a node where a field device is connected. When a handheld device is also connected on the network, it is called the secondary master.

A network having a large number of field devices can comprise one or more main buses, as well as additional secondary buses as in Figure 38.4.

To ensure that the cable will be able to support the HART signaling frequencies, the cable capacitance must be controlled. Too high of a cable capacitance value for a given "loop" resistance will attenuate the FSK signals. (Loop was shown in quotes because the network may no longer look like a loop, but total cable resistance must be used in the calculation with total cable capacitance.) Therefore, the RC time constant must be less than 65 µs. That means that the total capacitance of all of the cable of a given network multiplied by the total resistance must be less than 65. For example, 250 Ω × 0.26 µF = 65 µs.

OPEN SYSTEM INTERCONNECTION SEVEN-LAYER MODEL

Every network system has many activities and attributes that must be controlled in order to ensure that devices and software will work together. HART follows the "Open Systems Interconnection Reference Model," or Open System Interconnection (OSI), for short. More information on the OSI model can be found in Chapters 2 and 29. Here the OSI model will be explained as applied to HART networks.

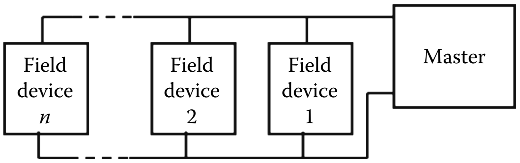

FIG. 38.3
Field devices multi-dropped in a HART network.

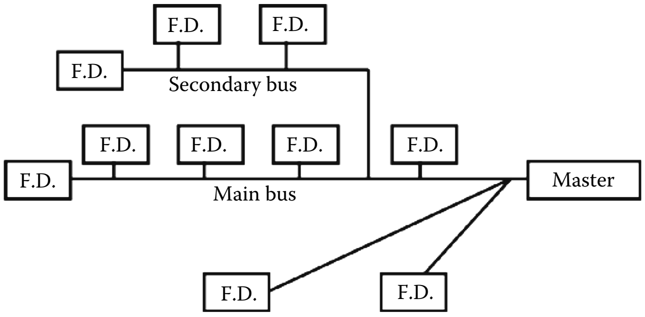

FIG. 38.4
Main bus, secondary bus, plus additional single Field Devices (FD).

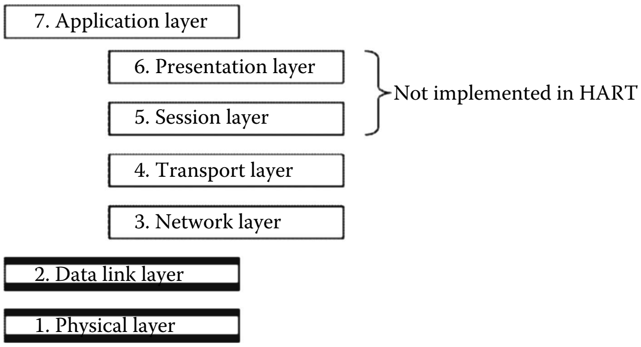

FIG. 38.5
The OSI seven-layer reference model. Layers 1–4 and 7 are implemented in HART.

The full OSI system specification has seven "layers." The term "layer" simply refers to a certain functional area, or section, of the total specification. The seven layers encompass the total communication structure of a network. Within each layer, one or more entities implement their particular functionality. Each entity interacts directly only with the layer below it, and provides facilities for use by the layer above it, with each layer being responsible for some discrete aspect of the networking process. Many devices, including those utilizing the HART protocol, are designed to operate without implementing all seven layers (Figure 38.5).

The OSI model describes the flow of data among devices connected together in a network, from the lowest layer (the physical connections, i.e., the two wires, voltages, currents, frequencies, resistance, capacitance specifications, etc.) up to the layer containing the user's applications. HART implements all of the layers except for 5 and 6, so, they will not be described here. (Note: it is often stated that HART implements only layers 1, 2, and 7. In that assessment, the functions included here as layers 3 and 4 are instead considered to be incorporated into layers 2 and 7, respectively.)

Layer 1: Physical

The physical layer uses a twisted pair of wires as the link over which to transmit bits of digital data using the Bell 202 FSK standard, in which 1200 Hz represents a digital "1" and 2200 Hz represents a digital "0" (Figure 38.6).

With an individual connection (i.e., only one HART device per twisted pair of wires), the loop current will vary with the measurand if the loop current is not parked. In Figure 38.6 however, the device current is parked at 4 mA, so that multidrop connection is possible (i.e., more than one HART device can be connected across the same twisted pair of wires). For ease of illustration, details of the 1200 and 2200 Hz signals are not shown, but the FSK frequencies would be included

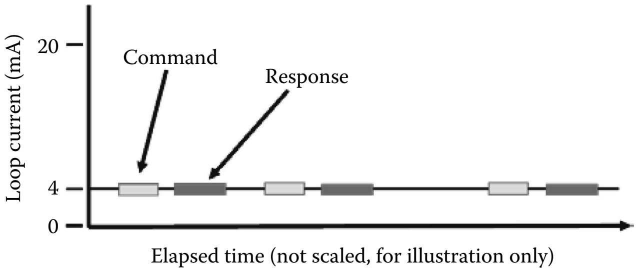

FIG. 38.6
FSK communication signal riding on the 4–20 mA current loop, loop current at 4 mA.

within each of the command and response time windows that are shown in Figure 38.6. Data rate is at 1200 baud (baud = bits per second), also called 1.2 kb. The two frequencies are sine waves, with amplitude of about ±0.5 mA if sent by a field device, or about ±0.1 V (i.e., 0.2 Vpp) if sent by a master. FSK current signals are converted to voltage at the internal resistance of the receiver (usually 250 Ω). The FSK currents or voltages do not affect the 4–20 mA analog current signal, because the HART protocol limits the bandwidth of the current signal to below 25 Hz. This is appropriate because a typical rate of change in signal current is in the 0–10 Hz range.

So, using the above method, the HART physical layer performs message modulation (changing into binary ones and zeroes) and carrier activation (1200 and 2200 Hz) for an outgoing message. For a message coming in, message demodulation and carrier detection are accomplished.

Later specifications include provisions for a higher-speed 9600 baud option. Revision 7 includes WirelessHART, which uses the 2.4 GHz Industrial, Scientific, and Medical [ISM] band) [4].

Layer 2: Data Link

The data link layer describes an asynchronous half-duplex protocol by which a master sends a command to a field device and by which the field device responds as necessary. The digital ones and zeroes (in binary, called "bits"), which are communicated by the FSK frequencies, are combined to form an ASCII character (American Standard Code for Information Interchange). The "characters" are the same as are marked on the keys of a keyboard (numbers, letters, punctuation, etc.). A set of eight binary bits ("data bits") is called a byte and a set of four bits is called a "nibble." The eight bits are used to represent each of the 256 possible characters. In order to properly send the data bits without error, additional bits, called start, parity, and stop bits, are sent with each character (Figure 38.7).

As shown in Figure 38.7, the time frame of sending one character (or byte) includes one start, one parity, and one stop bit, in addition to the eight data bits. So, the communication of one character comprises the time of sending 11 bits.

When a HART message is sent, each character is organized with start/stop/parity bits as was shown in Figure 38.7, and these are combined to form a message as shown in Figure 38.8, forming 1200/2200 Hz signals that were shown in Figure 38.6.

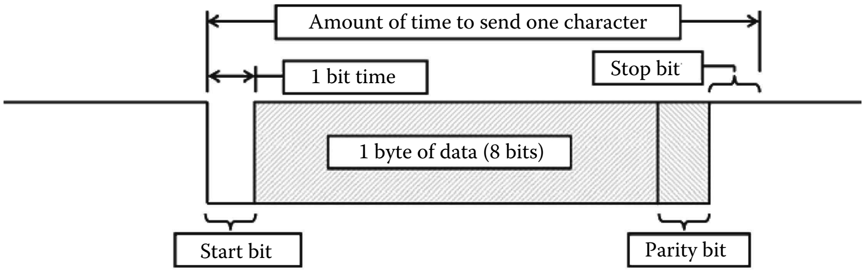

FIG. 38.7
Time frame of sending one character.

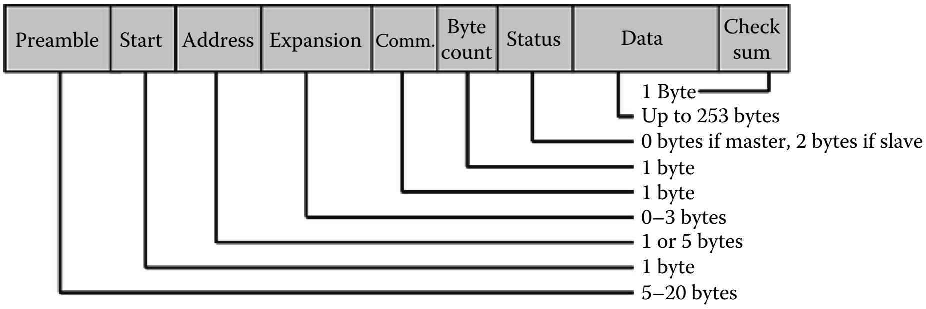

FIG. 38.8
The structure of one complete HART message.

The *preamble* of Figure 38.8 (5–20 bytes) comprises all logical ones, and provides a time period during which HART devices are getting ready to synchronize, when the next start bit will follow. The first bit of the start character is the start bit, and is a logical zero. The *start character* (1 byte) indicates the type of message (e.g., a message from the master, a burst message), short or long form address, and the length of the expansion field. The *address* field (1 or 5 bytes) includes the 38 bit long form address. Older units may contain the short form address of 4 bits (i.e., 4 binary bits represents base 10 addresses of 0–15). The *expansion* field (0–3 bytes) can contain up to 3 bytes of additional information. The *command* field (1 byte) instructs the field device what to do. The *byte count* (1 byte) indicates the number of bytes. The *status* field (0 bytes if master, 2 bytes if field device) is included only in the slave response, and indicates the slave status. The *data* field can include up to 253 bytes of information. The *checksum* (1 byte) is used for error checking.

HART communication is initiated by the master device. There is a primary master (usually the control system) and there can also be a secondary master (e.g., a handheld terminal for field use). Field devices respond after they have received a command message from a master. After a command and response cycle is completed, the master pauses to allow the other master to communicate, if needed. In a standard command, the master communicates with a specific field device. With a broadcast command, the command is received by all field devices on the network.

Some HART devices support the optional burst mode, in which a field device can cyclically send messages with short breaks in-between.

Layer 3: Network

The network layer provides switching and routing capabilities, creating logical paths for transmitting data. An example of an OSI model network layer is the Internet Protocol (IP), which together with the Transmission Control Protocol (TCP) of the transport layer, comprises the well-known TCP/IP. In HART networks, the network layer provides message transport, routing, security, and manages the sessions between communicating devices.

Layer 4: Transport

This OSI layer provides reliable data transfer, handling error recognition, and recovery. It breaks down long messages for transmission as suitably sized packets, and then rebuilds them at the receiving end. It keeps track of the packets and can retransmit any that fail. The best known example of a layer 4 protocol is the TCP. In the TCP example, the transport layer is the layer that converts messages into TCP segments. Like a post office, it classifies and dispatches the mail that is sent. In HART, the transport layer ensures that a message is successfully completed between one device and another.

Layer 7: Application

The application layer supports application and end-user processes. It is the level at which *applications* can access information and functions available on the network. An *application* is a module of software that can interface with the network. The application layer provides the means necessary to interact with an application, and therefore with the network. Application layer software can communicate through protocols such as File Transfer Protocol (FTP), Simple Mail Transfer Protocol (SMTP), and Hypertext Transfer Protocol (HTTP). With HART, the commands, responses, types of data, and status indication are supported, with the various types of commands being divided into three groups, comprising:

1. *Universal Commands* are intended for use by all field devices on the network.
2. *Common Practice Commands* provide utility functions available with most types of devices.
3. *Device Specific Commands* are specified by the device manufacturer to implement functions specific to that particular type of device.

The current set of HART commands can be found on the webpage: http://www.hartcomm.org/hcf/documents/appguide.pdf

A complete list of the HART Protocol specifications are sold as a set of over 20 documents by the HART Communication Foundation, for approximately $975 in 2010. The list can be seen at http://www.hartcomm.org/hcf/documents/documents_spec_list.html

In addition, other documents are available for purchase from the HART Communication Foundation. These include information required to support the development of a HART compatible device, as well as applications guide, calibration guide, etc. A list of these available documents can be viewed at: http://www.hartcomm.org/hcf/documents/documents_specifications.html

DEVICE DESCRIPTION LANGUAGE

The universal and common-practice commands allow use of the basic functions of all HART devices. These may provide sufficient functionality in systems mainly requiring access to the measured variables. But most HART field devices have additional functionality, supporting device configuration and management (e.g., diagnostics), and other features. The additional functions can be accessed according to their individual Device Description (DD), which specifies how to access these functions for a particular model of HART device. The HART Communication Foundation compiles a library of all the registered devices and their DDs. The library is updated quarterly and available to all HART Communication Foundation members.

A DD is an electronic data file that relates to a specific HART device, and is written in accordance with the specifications of the HART Device Description Language (DDL). The DD describes the functions and features of the device. The DD also provides details of graphic display features and menus for use by host applications and handheld devices. Thus, the DD provides means to access all of the data and functional parameters of the device. Most master devices have the capability to read the DD for their field devices. A list showing the latest release of the DD library is available at http://www.hartcomm.org/protocol/about/aboutprotocol_dd_library.html

Host system designers who want flexibility to work with any field device prefer to use DDs. In addition to being able to configure the field device, using the DD also provides access to any available diagnostic information, such as a warning of a potential failure, or possible causes of an actual failure.

When viewing a listing of a DD, the format has an appearance along the lines of a program listing that is written in "C." Something similar to HART DD is also utilized in FF, except that, whereas HART uses individual commands, FF uses references to the object dictionary. The HCF offers courses for engineers to learn how to write a DD for their product.

LONG ADDRESS VS. SHORT ADDRESS

In earlier versions of HART (before revision 5), the address field comprised four binary bits. This allowed for addressing up to 16 devices, 0–15. If the short address of a device (also called the polling address) is zero, then it provides the normal 4–20 mA signaling (i.e., not networked). But if the short address is not zero (i.e., 1–15), then the current is parked at 4 mA, and the device is configured for network connection (i.e., allows more than one device on that particular pair of wires). The use of devices of revision level less than 5 is no longer recommended, and such devices may not be supported by new systems or software.

Later revisions (revision 5 or later) implement a 38 bit address, of which the 4 least significant bits are the same as the short address. With these later revisions, only command 0 may be sent along with the short address. At an appropriate time, such as when a field device is first connected, it can be sent its short address along with command 0, and the field device will return its long address (the long address is also available in response to command 11). The master device will then copy and use this long address for any further communications with that device. The long address comprises a device ID number (16 bits), the device type (16 bits), and the 6 least significant bits of the manufacturer's ID (Figure 38.9). The manufacturer of the device must ensure that the device ID number is unique for a device of that particular device type. The device type is assigned by HCF for each new field device. The complete form of the manufacturer's ID is 16 bits, and is reported in an extension of the command 0 response.

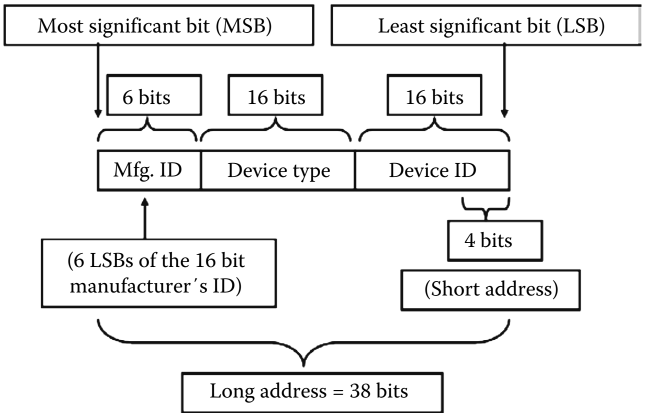
Most significant bit (MSB)
Least significant bit (LSB)
6 bits
16 bits
16 bits
Mfg. ID
Device type
Device ID
4 bits
(6 LSBs of the 16 bit manufacturer's ID)
(Short address)
Long address = 38 bits

FIG. 38.9
The HART Long Address comprises 38 binary bits.

COMMUNICATION SPEED

The signaling speed for HART communication is 1.2 kbps. From Figure 38.8, and assuming typical messages from master and slave, a message sequence would typically contain approximately 38 bytes. That assumes 4 bytes for data (master or slave), no expansion, long address, and a 5 byte preamble. That is, 18 bytes for the master command, including preamble: 5, start: 1, address: 5, expansion: 0, comm: 1, count: 1, status: 0, data: 4, and checksum: 1. The 20 byte slave response includes all of the same, plus a 2 byte status. So, in this example, the total number of bytes for the master command and the slave response is 38 (18 + 20 = 38). Figure 38.7 showed that each byte of the 38 bytes comprises 11 bits (8 data, 1 start, 1 parity, 1 stop). So 38 bytes multiplied by 11 bits equals approximately 418 bits per message and response. At a signaling speed of 1.2 kbps, the total time would be 0.35 s (418 bits divided by 1.2 kbps). Add in some time between messages, and the message and response time will round out to about 0.38 s. Of course, if there is only one device on the loop, its polling address can be set to 0 and the loop current will be available as fast as the device can provide that (which is usually around 0.1 s). So with various numbers of field devices on the network, Table 38.1 shows the amounts

TABLE 38.1
Number of Devices on a Network vs. Communication Times

Number of Devices on Network	*Total Time for Updates from All Devices (s)*
1	0.38
4	1.52
8	3.04
16	6.08

of time that would be required in order to receive information from all devices on the network.

Accordingly, due to the extended times listed in the table, it may be difficult to operate an industrial control system with HART devices when several devices are connected in a network configuration. But a single HART device is certainly fast enough for many control systems, and the current loop may be used if a faster control loop is needed.

INSTALLING HART CONTROLLERS AND FIELD DEVICES

The HART master, which is the host of a network, is hardwired into the network. But to the contrary, a handheld HART master is typically connected as needed, in parallel across a field device. The handheld master can be routinely connected or disconnected while the system is operating, since the network is not interrupted.

Wiring

For short network distances (less than 100 m), it is possible to use a pair of unshielded wires (with conductors of at least 0.2 mm diameter, or 32 AWG). Even for short runs, it is preferred that the pair be twisted, but may be untwisted if there is minimal exposure to EMI (Electromagnetic Interference) and to cross-talk signals (i.e., capacitive or inductive coupled signals from adjacent wires, e.g., placed together in a raceway). However, it is recommended to use a twisted pair with wire diameter of at least 0.51 mm (24 AWG), with a cable shield, for all cable lengths up to 1500 m. For cable lengths over 1500 m, a twisted pair having conductors of at least 0.81 mm diameter (20 AWG), with a shield over the pair, should be used. The theoretical limit for cable length is 3,000 m (10,000 ft). It is also important to make sure that the cable capacitance is less than the maximum allowed for the system configuration. See the table with this information at: http://www.hartcomm.org/protocol/using/usinghart_wirelength.html

Primary or Secondary Master

In addition to the various HART master devices that are available from instrument suppliers, there is also the possibility to use a PC as the master, with interface to the network via RS-232 or RS-485. Converters to HART from RS-232 or RS-485 are available from instrument suppliers. Software for using the PC with HART networks is available from some instrument manufacturers as well as from software suppliers. A partial list of such software is available at http://www.hartcomm.org/hcf/documents/appguide.pdf

Before installing a field device, it is helpful to connect it to a handheld in order to verify that the manufacturer's data for the device conforms to the application requirements. If the configuration needs to be altered, it may be easier to do it in the control room than on the manufacturing floor. Once all of the field devices are installed, each one should be verified to ensure that there is proper communication. The loop test feature can be called in order to check loop integrity, by imposing a particular current into the loop and checking various indicators, etc. for proper function.

Intrinsic Safety

Many industrial process and storage installations must meet IS requirements. In addition to installing only IS rated devices, and observing that maximum loop capacitances are not exceeded, a barrier device is normally required. An intrinsically safe field device can be mounted in a hazardous area (e.g., an area that may contain flammable or explosive mixtures of flammable gas and air) when used with an appropriate safety barrier. The safety barrier is mounted in a safe area, and provides the wiring link between the safe area and the hazardous area. The safety barrier limits the energy to below that, which is needed to cause ignition of a flammable gas, vapor, fibers, etc., by limiting the voltages and currents available to the hazardous area to levels below those that could allow formation of a spark having sufficient energy to ignite the specified range of flammable atmosphere. The IS field device inductance, capacitance, and maximum spot temperature are likewise limited to retain that inability to cause ignition, when used together with the applicable barrier device.

It is possible to use a shunt-type IS barrier (a passive barrier), since they are the least expensive, but it is often easier to use an active type of barrier. That's because the shunt barrier will have a substantial amount of internal resistance, which must be included in the loop resistance calculation. And the protection provided by a passive barrier is with respect to earth ground. Active barriers, however, contain electronic circuits that can eliminate the loop resistance problem, as well as maintain isolation from earth ground, if desired.

Calibration

The calibration of field devices can be verified before installation, and routinely thereafter during scheduled maintenance. This includes calibration of the digital process value(s), as well as scaling for the 4–20 mA current loop. HART commands can assert a particular loop current to verify accuracy of the loop current. Other commands are used to trim or rescale a transmitter or actuator. When measuring a PV, the variable will have an operating range. For example, that range could be 0–50 PSIG. When trimming the transducer, two points are selected somewhere along the measurand vs. output transfer function, near the endpoints. The transducer is subjected to these inputs (e.g., 0 and 45 PSIG). Adjustment is made, if needed, to link the proper digital values corresponding to these inputs. The digital values are then assumed to be accurate throughout the selected range, subject to the stated nonlinearity, etc. of the field device (e.g., throughout the range of 0–50 PSIG). The digital values are then mapped to the desired percent values, for example, 0–50 PSIG can correspond to 0%–100%. Last, the percent values are mapped to the desired current loop output, for example, 4–20 mA ending up with 0–50 PSIG corresponding to 4–20 mA loop current, as well as digital values.

HART calibrators are available that provide a simulated process signal, and determine if calibration or trimming is required. If adjustment is needed, the calibrator issues appropriate HART commands, and the results are recorded. In the proposed example, the process zero is 0 PSIG and the span is 50 PSIG (the process full scale is also 50 PSIG). The loop current zero is 4 mA and the span is 16 mA (20 mA is the full scale).

Troubleshooting

When troubleshooting a completed HART installation, check to make sure that the proper addresses are assigned. If a modem is connected to a PC, make sure that the correct port of the PC has been selected (e.g., COM 1 or COM 2). Ensure that the power supply is capable of supplying all of the devices that are connected on the network, and that the power supply is providing the stated voltage. Check cable lengths, resistances, and capacitances to make sure that they are within requirements.

HOST CONFORMANCE CLASS

Hosts should be able to initiate communication and identification with all field devices. But field devices have various capabilities, all of which may or may not be available for access with a given host. The capability of a host to utilize various ranges of possible functions is called its conformance class. Classes 1 through 5 correspond to a host having basic communications capability, through one having nearly universal capability, respectively (Table 38.2).

Conformance Class 3 is generally considered to indicate a generic host, capable of handling all commands usually needed for most installations.

REVISIONS OF THE HART PROTOCOL

Since the last revision of this reference book was published in 2003, there have been several revisions to the HART protocol since then. The major revisions were 6.4, 7.0, and 7.1.

Revision level 6.4 provided for the 16 bit manufacturer ID, which is supplied by HFC. Revision 7.0 comprised some extensive enhancements, including WirelessHART™, command numbers 77, 84–104, 512, 513, 768–1023. The command numbers 768–1023 pertain to the new WirelessHART. 7.0 also includes some extended commands, trend data, command aggregation and, publish on exception. Command numbers 38 and 48 became universal 7.0. This short listing is intended to provide some general information regarding the revisions. A more detailed and complete revision listing is available from the HCF.

WIRELESS HART

As noted above, revision 7.0 provides support for WirelessHART. This low-power wireless system operates in the unlicensed 2.4 GHz ISM radio band. It will function with up to about 200 m between communicating devices. It operates with a mesh structure, which means that multiple communication paths may be present, and also allows for corrections in the case of a communication problem (i.e., if one wireless path fails, another path can be used, if available).

The data link layer uses a method called Time Division Multiple Access (TDMA) instead of the token passing method used with the FSK signals of the wired HART. The specification of WirelessHART is extensive, and beyond the scope of this present chapter. Detailed specifications of WirelessHART are available online from the HCF website.

TABLE 38.2
Host, Or Master, Device Conformance Classes vs. Their Capability to Utilize the Various Types of Field Device Commands

		Host Can Utilize These Slave Command Types		
Conformance Class (Host)	*Communication Function*	*Universal*	*Common Practice*	*Device Specific*
1	Read PV	×		
1A	Read universal information	×		
2	Write common practice parameters	×	×	
3	Read device-specific information	×		×
4	Write selected parameters	×	×	
5	Read and write entire database	×	×	×

BENEFITS OF HART AND COMPARISON WITH FF

The HART protocol provides some important features:

- Can operate with the wiring of an installed base of two-wire transmitters
- Relatively simple system that is easy to operate and maintain
- Proven designs, with many systems installed since the early 1990s
- Compatible with conventional analog instruments and indicators
- Simultaneously provides analog and digital signaling
- One field device can communicate several variables
- Can use one device per current loop, or multi-drop
- Response time of less than 1 s is adequate for most indication uses
- Open system, available to all users
- Remote master can be used in addition to the main controller
- Analog signal can be compared to the digital message to verify operation

Compared to FF

There is no alternative to HART, as an open system for providing both analog and digital communication over the same pair of wires. FF is an open standard that is suitable for process control equipment, but provides only digital signaling. While HART provides for a virtually unlimited number of devices, practically speaking, the FF standard supports up to 32 devices on a given pair of wires. But that is not normally a limiting factor in deciding on which system to use. A major advantage of FF is the signaling speed of 31.5 kbps vs. the 1.2 kbps speed of HART. Although the FF signaling speed is much greater than with HART, the message communication speed is not increased by the same factor, due to the increased number of bits transmitted per FF message. FF-based devices are more complex, generally require more software, and use a greater amount of power, than “equivalent” HART devices.

CONCLUSIONS AND COMMENTS

Since early HART systems only had handheld communicators available as the master, the protocol became known as useful for its setup, calibration, and diagnostic functions. But today’s systems have proven capabilities for industrial indication and analysis. With digital communication speeds of less than 1 s in many systems, it is also suitable for some lower-speed control applications.

HART systems have many positive attributes, including that they are simple, proven, and easy to maintain, also being compatible with conventional current loop instrumentation. Simultaneous analog and digital communication is available when not networked. In addition to the normal master, an additional master can be used for maintenance, etc., via a handheld device.

So, for systems where the digital communication speed is sufficiently fast, systems using the HART protocol have many advantages and continue to be an effective and popular choice.

References

1. Brignell, J., *Intelligent Sensor Systems*, Philadelphia, PA: Institute of Physics Publishing, p. 214, 1996.
2. Frank, R., *Understanding Smart Sensors,* Boston, MA: Artech House, p. 111, 1996.
3. Nyce, D. S., *Linear Position Sensors, Theory and Application*, Hoboken, NJ: John Wiley & Sons, p. 32, 2004.
4. HART Communication Foundation, *HART Technical Overview*. WWW.hartcomm.org (accessed on March 20, 2011.).